

Enzymes and metabolism

Revision notes · IB Biology C1.1: enzymes as catalysts, metabolism, active sites and induced fit, factors affecting rate and activation energy.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

Enzymes and metabolism Spec C1.1

Enzymes as catalysts and their role in metabolism Spec C1.1.1, C1.1.2, C1.1.3

An **enzyme** is a protein that acts as a **biological catalyst**: it increases the rate of a chemical reaction and is not changed or used up by the reaction, so one enzyme molecule can be used again and again.

Without enzymes, most reactions in cells would happen far too slowly at body temperature to keep the organism alive. Raising the temperature enough to speed them up would damage cell structures.

Enzymes give fast rates at the moderate temperatures found in cells, and the cell can switch reactions on or off by making, activating or inhibiting particular enzymes.

Metabolism

Metabolism is the complex network of interdependent and interacting chemical reactions occurring in living organisms. The product of one reaction is often the substrate of the next, so reactions are linked into pathways, and pathways share molecules with each other.

Enzymes are **specific**: each one catalyses one reaction or one type of reaction. Living organisms therefore need many different enzymes, often thousands. Because every step depends on its own enzyme, control over metabolism can be exerted through these enzymes, for example by changing how much of an enzyme is made or how active it is.

Anabolic and catabolic reactions

The two types of metabolic reaction		
	Anabolism	Catabolism
What happens	Larger molecules built from smaller ones	Larger molecules broken down into smaller ones
Typical reaction	Condensation: monomers joined, water released	Hydrolysis (water used to split bonds) or oxidation
Energy	Needs an energy input (usually from ATP)	Often releases energy
Examples	Protein synthesis (amino acids joined by peptide bonds); glycogen formation from glucose; photosynthesis (carbon compounds made from CO ₂)	Hydrolysis of macromolecules into monomers in digestion; oxidation of substrates such as glucose in respiration

Anabolism	Reactions that build macromolecules from monomers, for example by condensation.
Catabolism	Reactions that break down macromolecules into monomers, for example by hydrolysis, or oxidise substrates as in respiration.

Common mistake: Photosynthesis is anabolic and respiration is catabolic. Do not describe digestion as anabolic just because it happens before new molecules are built.

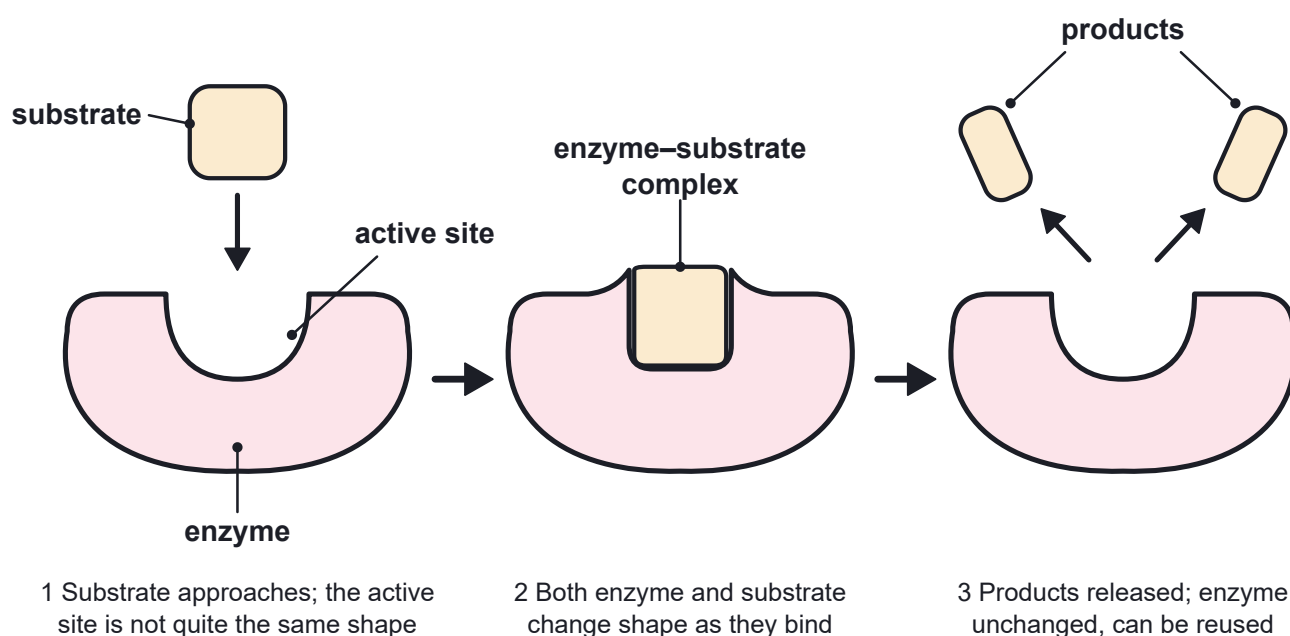
Active sites, induced fit, collisions and denaturation Spec C1.1.4, C1.1.5, C1.1.6, C1.1.7

Enzymes are **globular proteins**. The polypeptide is folded into a compact, roughly spherical shape that is usually soluble in water. Part of the surface forms the **active site**, the region where the substrate binds and the reaction is catalysed.

The active site is made of only a **few amino acids**. Their R groups give it a particular shape and chemical properties (charge, polarity, hydrophobic areas). But these few amino acids are held in exactly the right positions by interactions between amino acids throughout the rest of the protein (hydrogen bonds, ionic bonds, disulfide bonds and hydrophobic interactions). The whole three-dimensional structure is needed for the active site to work.

Induced-fit binding

The substrate binds to the active site by chemical attraction between them. In the **induced-fit** model, both the substrate and the enzyme change shape when binding occurs. The active site moulds more tightly around the substrate, which stresses bonds in the substrate and makes them easier to break or form. The products are then released and the active site returns to its original shape.



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Induced fit: **both the enzyme and the substrate change shape** as the substrate binds to the active site.

Molecular motion and collisions

For a reaction to be catalysed, a substrate molecule and an active site must **collide**, in a suitable orientation. Enzymes and substrates dissolved in water move randomly, and these collisions happen by chance. Sometimes only one of them moves: large substrate molecules (such as starch in a starch grain

or cellulose in a cell wall) may be immobilised while enzymes move to them, and some enzymes are immobilised by being embedded in membranes while their substrates move to them.

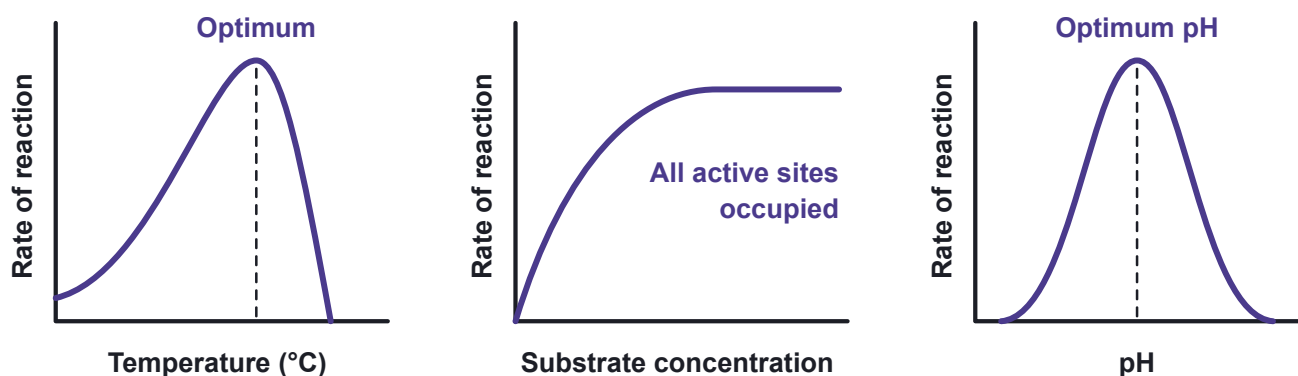
Specificity and denaturation

Enzyme-substrate **specificity** exists because only a substrate with a shape and chemical properties that match the active site can bind to it. Change the structure of the active site and binding fails.

Denaturation is a change to the three-dimensional structure of the protein, caused by high temperature or extreme pH. Bonds holding the tertiary structure break, so the active site changes shape and its chemical properties change. The substrate can no longer bind, so the enzyme cannot catalyse the reaction. Denaturation is usually permanent.

Exam tip: When explaining denaturation, link the chain: bonds in the tertiary structure break, the active site changes shape, the substrate no longer fits or binds, so no enzyme-substrate complexes form.

Effects of temperature, pH and substrate concentration Spec C1.1.8, C1.1.9



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Generalised sketch graphs for the effects of temperature, substrate concentration and pH on the rate of an enzyme-catalysed reaction.

Temperature

As temperature rises, enzyme and substrate molecules have more kinetic energy and move faster. Collisions between substrate and active site become more frequent and more of them have enough energy to react, so the rate increases. Above the **optimum temperature**, the extra vibration breaks bonds holding the enzyme's structure; more and more enzyme molecules denature, so the rate falls steeply. The curve is not symmetrical: the fall is much steeper than the rise.

pH

Each enzyme has an **optimum pH**. A change in pH alters the concentration of hydrogen ions, which changes the charges on R groups in the active site and elsewhere. Ionic and hydrogen bonds are disrupted, so the substrate binds less well and the rate falls on either side of the optimum. Far from the optimum the enzyme is denatured. For example, pepsin in the stomach works best in acid conditions, while many enzymes in the small intestine work best near neutral pH.

Substrate concentration

At low substrate concentrations, raising the concentration increases the frequency of substrate-active site collisions, so the rate rises steeply. As the concentration increases further, more active sites are occupied at any moment, so the rise slows. Eventually **all active sites are occupied** nearly all the time and the rate levels off at a maximum. Enzyme concentration is then the limiting factor.

Exam tip: Sketch graphs like these are models. They can be evaluated by comparing them with real results from enzyme experiments. When describing a graph, give the trend, the optimum or the plateau, and quote values with units.

Measurements in enzyme-catalysed reactions

The rate of an enzyme-catalysed reaction is measured as the amount of **product formed** or **substrate used** per unit time. Common methods include measuring the volume of oxygen released when catalase breaks down hydrogen peroxide (gas syringe or displacement of water), and timing how long starch takes to disappear when amylase acts on it (samples tested with iodine). Rates can also be found from secondary data.

- Mean rate = change in amount $\div$ time taken.
- Initial rate: draw a tangent to the curve at time zero and find its gradient. This is the fairest comparison because the substrate concentration has not yet fallen.
- If only a time is measured (for example, time for starch to disappear), rate can be expressed as $1 \div$ time.

Calculating rates from enzyme data

Catalase was added to hydrogen peroxide. 18 cm³ of oxygen was collected in the first 30 s and 30 cm³ by 90 s. Calculate the mean rate over the first 30 s and over the whole 90 s.

1. First 30 s: rate = $18 \text{ cm}^3 \div 30 \text{ s} = 0.60 \text{ cm}^3 \text{ s}^{-1}$.
2. Whole 90 s: rate = $30 \text{ cm}^3 \div 90 \text{ s} = 0.33 \text{ cm}^3 \text{ s}^{-1}$.
3. The rate falls over time because substrate is used up, so there are fewer collisions with active sites.

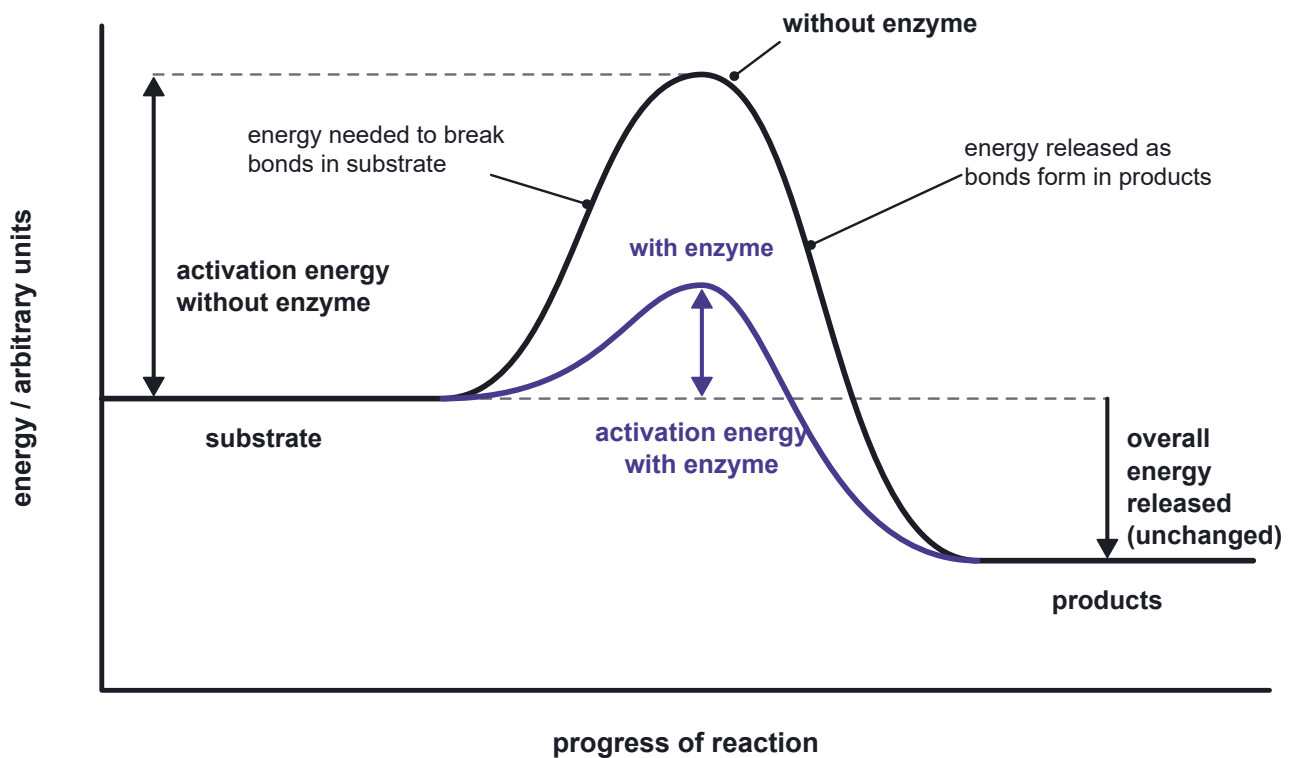
Answer: 0.60 cm³ s⁻¹ over the first 30 s; 0.33 cm³ s⁻¹ over 90 s.

Practical skill: Control temperature with a thermostatically controlled water bath, pH with buffer solutions, and keep enzyme concentration and volumes constant. Repeat each condition at least three times and calculate a mean.

Effect of enzymes on activation energy Spec C1.1.10

Before a reaction can happen, bonds within the substrate must be broken or weakened. This needs an input of energy called the **activation energy**. When new bonds form to make the products, energy is released (the energy yield). In many metabolic reactions the products have less energy than the substrates, so there is an overall release of energy.

Enzymes **lower the activation energy**. Binding to the active site stresses and weakens bonds in the substrate, so less energy is needed to reach the transition state. A larger proportion of substrate molecules then have enough energy to react, and the reaction is faster at the same temperature. The enzyme does **not** change the energy of the substrates or the products, so the overall energy change is unchanged.



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Enzymes **lower the activation energy**, measured from the substrate level to the peak; the overall energy change is unchanged.

Exam tip: On an energy graph, the activation energy is measured from the substrate level to the peak, not from the products or from zero.

Exam tip: Linking question: enzymes are a clear structure–function relationship in a macromolecule. The folded polypeptide creates an active site that lowers activation energy for one specific reaction.

Quick check

1. What is metabolism?
2. Give one example of an anabolic and one of a catabolic reaction.
3. In the induced-fit model, what changes shape when the substrate binds?
4. What happens to the activation energy and the overall energy change when an enzyme catalyses a reaction?

Quick check answers

Enzymes and metabolism

1. The complex network of interdependent and interacting chemical reactions occurring in living organisms.
2. Anabolic: protein synthesis, glycogen formation or photosynthesis. Catabolic: hydrolysis in digestion or oxidation of glucose in respiration.
3. Both the substrate and the enzyme's active site.
4. The activation energy is lowered; the overall energy change is unchanged.